

This is a report by  
Dr Malcolm Coulthard

requested by the *Inquiry into Hyponatraemia-Related Deaths*

to present an argument that an error in zeroing Adam's CVP transducer  
is likely to explain the pattern of pressure measurements observed during  
his transplant operation

15/03/2012

## Further considerations about the CVP measurements made in Adam Strain

### Was the CVP line reflecting intra-thoracic pressure changes?

The only evidence that we have about whether the pressure measured from the CVP line in Adam was monitoring his intra-thoracic pressure, or if it was obstructed in a neck vein and recording that blocked vein's drainage pressure, is that Dr Taylor stated that there were both respiratory and cardiac wave-forms seen on the trace. If this was true, then it conclusively demonstrates that the tip of the intravenous line was in direct continuity through a fluid path with the blood in his chest, that is that the pressure recording **was** reflecting his CVP.

In the absence of any recorded traces from his monitor to confirm whether there were respiratory and cardiac pressure changes present (the ones available being set at a time scale which is not able to detect them), it is reasonable to assume that there were since Dr Taylor stated this, and therefore that the CVP line **was** patent. Any arguments that are based on the assumption that the line tip was jammed into a vein have to address this point directly, as they are by definition invalid if we accept Dr Taylor's statement.

### Do Adam's pressure readings make physiological sense?

The reason why Dr Taylor considered that there must have been a problem with the CVP readings at the start of surgery is that they were not consistent with the other evidence of Adam's physiology. All of the other evidence about him, including his normal clinical appearance, the fact that he was in approximately neutral fluid balance (or even depleted according to the fluid assessment that Dr Taylor made then, but has subsequently retracted), and his normal pulse (for a boy facing the anxiety of an operation) and blood pressure.

A venous pressure of 17 mm Hg (24 cm of water) is very high, and is indicative of a medical problem rather than a physiologically stable and normal state, either due to fluid overload or a serious abnormality of the cardiovascular system, which Adam did not have.

The finding of a high CVP in a child where the clinical history and other physical signs indicate that it would be expected to be normal therefore indicates that there was probably a technical problem with the CVP measurement. This is the conclusion that Dr Taylor reached. However, instead of solving what the problem was, he decided to ignore the absolute pressures being recorded, and to follow its changes instead, using these trends to inform him of Adam's physiological responses. In the event of Adam's recorded CVP values then increasing beyond a level that Dr Taylor had expected or could explain (given that he remained convinced that Adam remained dehydrated during the operation), he decided instead to ignore the readings altogether, and to continue to infuse fluids at a high rate as if the true CVP was much lower than was being recorded.

Until now, a number of the experts (including myself) have postulated either that the CVP readings were invalid because the venous catheter was obstructing the lumen of the vein it was in, or have simply been unable to explain its high initial values or trends. During the meeting of 09/03/12, however, it occurred to me that the measurements could be best explained by postulating a persistent zeroing problem of the CVP equipment while Adam was in theatre.

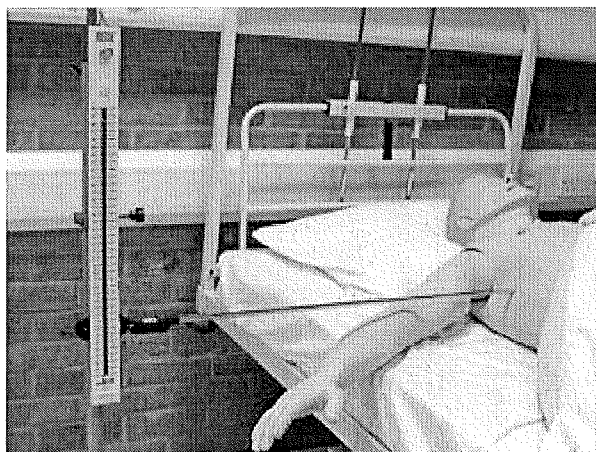
### How are CVP lines calibrated?

The CVP is a measure of the venous pressure in the most central of the veins as they return blood to the right atrium of the heart. In clinical practice it is assumed that the level of the right atrium can be estimated from markers on the outside of the chest, namely to be at the level of the 4<sup>th</sup> intercostals space (ie, just below the 4<sup>th</sup> rib) in the mid-axillary line with the patient in a supine position.<sup>1</sup>

Most texts simply instruct the operator to calibrate the CVP measurement device to read a pressure of zero in relation to the atmosphere at that horizontal level.<sup>1</sup> Using a pressure transducer, this process of zeroing is achieved by briefly closing the tap connecting the device to the patient's line, and opening it instead to the atmosphere while it is fixed at the correct horizontal level, and then closing that port and reverting back to the patient line connection. If the patient's position is moved, then a re-zeroing manoeuvre has to be repeated.



In many clinical settings the zeroing process is simple because the patient's chest can be easily approached to allow the transducer to be set at the same horizontal level. In PICU settings, for example, the transducer is sometimes actually taped to the child's chest wall directly. However, in many other situations such close proximity is not convenient, and the transducer needs to be zeroed while it is physically some distance from the patient. This is usually managed by using a sufficiently long spirit-level, so that one end of this instrument touches the child's chest while the other end touches the transducer, usually clamped onto a wheeled drip stand. While water manometers may be supplied with an inbuilt spirit-level (see the figures below taken from a pamphlet published by the author of paper 1), electronic transducers do not, and it is common practice to use a spirit level such as a builder or DIY worker might use.



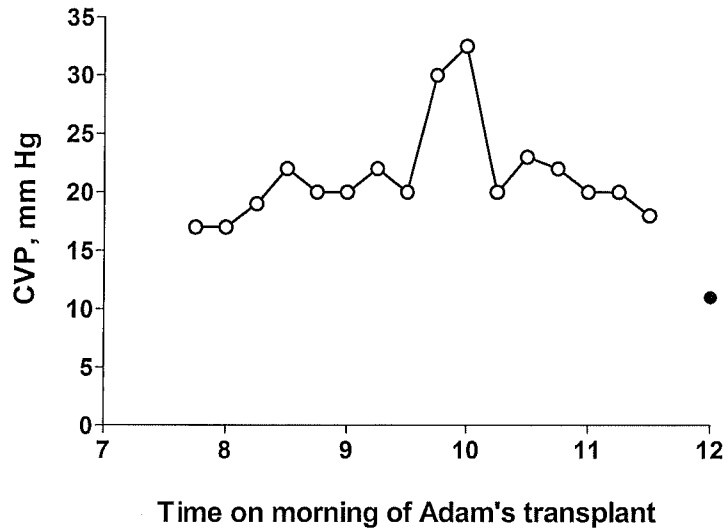
There is plenty of room for error in using a standard DIY-type spirit level, as many a wonky shelf will attest to. First there is the problem of whether the horizontal point at the child's end was correctly aligned, since Adam would have been under sterile towels during his time in theatre. Secondly, there is the question of whether the operator using the spirit-level was competent at ensuring that the bubble was correctly aligned between the 2 marker lines, rather than perhaps being lined up with its mid-point coincident with a line.

Finally, and in my opinion most likely, is the question of which edge(s) of the spirit level was (were) used as the reference point(s). For example, if the operator (presumably the anaesthetist) who held the patient's end of the level lined the correct anatomical point up with the top edge of the spirit level (partly hidden by green towels from the other operator's vision) while the second operator (say a theatre nurse), who was a metre away at the other end of the spirit level, lined up the transducer with the bottom edge of the level, then the transducer would be too low by the width of that particular spirit level. My own long spirit-level is 1 metre long and 12 cm high when held in the correct alignment to make such a reading, so in that case such an error would increase the measured pressure by 12 cm of water, or about 9 mm Hg. And if this exercise was repeated during the operation without the error being recognised, it would produce a systematic error throughout. The practical difficulties in achieving accurate CVP placement in theatre were raised a decade before Adam's operation.<sup>2</sup>

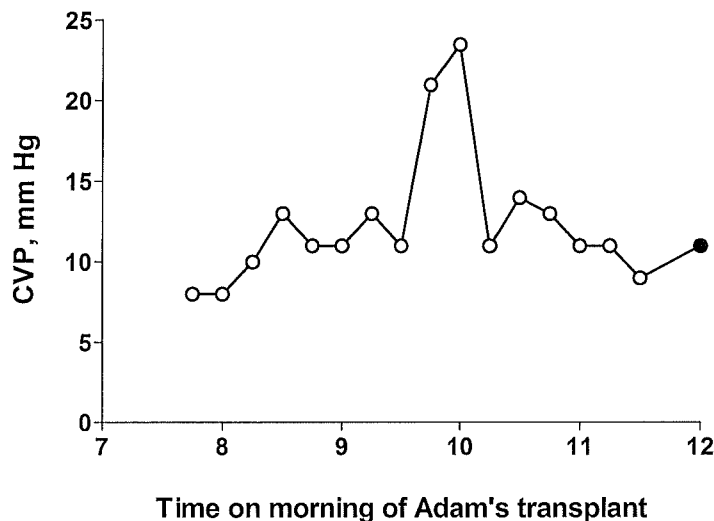
**Could such a systematic error explain the readings in Adam?**

If the readings in theatre had been made with a spirit-level such as my own one, and a systematic error of 9 mm Hg introduced, and if he had then been transferred to PICU where a direct alignment of the transducer would have been much easier to achieve, what would you expect to see in his CVP trace measured shortly after the transfer? I argue that there would be an otherwise unexpected drop in apparent CVP between the end of theatre and being checked again in PICU.

The following graph shows the actual readings, with the theatre ones as open circles, and the PICU one as a solid dot. There is a fall of 9 mm Hg between theatre and PICU as predicted.



If a value of 9 mm Hg is subtracted from all of the theatre figures, but not from the PICU measurement, we see the following graph:



Much of this pressure trace now makes good clinical sense. Though the initial value is not quite as low as might be expected in most children arriving in theatre, the first reading was taken at 07:45 am, after about 500 ml of 0.18% saline had been infused over just  $\frac{3}{4}$  of an hour. Though N/5 saline is regarded as a fluid that is not retained well within the vascular compartment as it contains so little sodium, it will of course not have had time to dissipate fully into his cells (including his brain cells) at this time as it was still being actively infused.

Thereafter, Adam's total fluid overload continued to increase until the vascular clamps were opened to the kidney, and we see that generally reflected in a trend to rise and fall gently over that time-frame. I cannot explain why his CVP would have read as high as 20 and 22.5 during the time that the kidney was being sutured in, however.

The PICU value then simply appears to be an extension of the previous values, with no step-down to explain.

### Conclusion

It will never be possible to know for certain why Adam's CVP trace appeared as it did. However, it is not reasonable to assume that the central line blocked the vein since the only record indicates that it had a thoracic pressure wave form, nor that it became un-blocked coincident with him being transferred from theatre to PICU when in fact his head position would have been less downward, a change that would result in the tip of the central line moving further along the lumen of the vein. Instead, the best explanation, and an entirely feasible one, is that the transducer was consistently positioned about 12 cm too low in theatre, due to the practical difficulties in achieving an accurate horizontal line.

### Suggestion

For years, I have used a long length of water-filled oxygen tubing as a spirit-level substitute in this situation, and did so before 1995. It allows a precise horizontal level to be achieved completely reliably regardless of the practical obstructing equipment present in theatre or PICU. One operator simply holds his/her end of the tubing at the child's chest, while the other operator holds their end next to the transducer, and the middle length can follow any path it needs to in-between them. When the fluid level by the child is at the mid-axillary line, and the other fluid level is mid-transducer level, they must be equal. It is a shame I did not publish this years ago, as it may have helped in this particular situation – I will do so swiftly now.

### References

1. Cole E. Measuring central venous pressure. *Nursing Standard* 2007;22:40-42.
2. Bar ZG. Zeroing the CVP. *Intensive Care Medicine* 1985;11:226.

**Expert Witness Declaration**

I Malcolm Coulthard DECLARE THAT:

- 1) I understand that my duty in providing written reports and giving evidence is to help the Court, and that this duty overrides any obligation to the party by whom I am engaged or the person who has paid or is liable to pay me. I confirm that I have complied and will continue to comply with my duty.
- 2) I confirm that I have not entered into any arrangement where the amount or payment of my fees is in any way dependent on the outcome of the case.
- 3) I know of no conflict of interest of any kind, other than any which I have disclosed in my report.
- 4) I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.
- 5) I will advise the party by whom I am instructed if, between the date of my report and the trial, there is any change in circumstances which affect my answers to points 3 and 4 above.
- 6) I have shown the sources of all information I have used.
- 7) I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.
- 8) I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.
- 9) I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing lawyers.
- 10) I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.
- 11) I understand that;
  - 11.1) my report will form the evidence to be given under oath or affirmation;
  - 11.2) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;
  - 11.3) the court may at any stage direct a discussion to take place between experts for the purpose of identifying and discussing the expert issues in the proceedings, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;
  - 11.4) the court may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;
  - 11.5) I may be required to attend court to be cross-examined on my report by a cross-examiner assisted by an expert;
  - 11.6) I am likely to be the subject of public adverse criticism by the judge if the Court concludes that I have not taken reasonable care in trying to meet the standards set out above.
- 12) I have read Part 35 of the Civil Procedure Rules and the accompanying practice direction including the "Protocol for Instruction of Experts to give Evidence in Civil Claims" and I have complied with their requirements.
- 13) I am aware of the practice direction on pre-action conduct. I have acted in accordance with the Code of Practice for Experts.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. The opinions I have expressed represent my true and complete professional opinions on the matters to which they refer.

Signed  Dr Malcolm Coulthard

Dated 15/3/12 15/03/2012

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